# Mitigation of Harmonic Current through Hybrid Power Filter in Single Phase Rectifier

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***Abstract*— This paper presents a single-phase Hybrid Power Filter (HPF) for harmonics and reactive power compensation. This proposed topology reduces the rating and size of the filter components. A combination of Passive and Active Filter is proposed for reducing the rating of filter. In the proposed technique Passive Filter (PF) is tuned to compensate 3rd and 5th order harmonics and Active Power Filter (APF) compensates all remaining harmonic components which are not compensated by passive filter. A half bridge inverter with DC bus capacitor is used as active filter. It has only two power switches. The active power filter control is based on DC side voltage control. The effectiveness of the proposed algorithm is demonstrated by its simulation in PSIM software. The simulation results show that the designed hybrid filter compensate the harmonic currents produced by loads and the power factor, making the current at the source side to become sinusoidal and in phase with the system voltage.**

***Key Words*— Active power filter, Harmonics, Passive filter, Power quality.**

## I. Introduction

With the progress of power electronics, researchers started the development of electronically controlled devices that have non linear current consumption. These devices were primordially developed to increase the energy efficiency and the controllability of advanced production processes, but, since they produce harmonics, these devices are now responsible for extra energy losses and bad operation of the electrical distribution system and its components [1]. Many of harmonic sources are single-phase loads, such as computers, fluorescent compact lamps, copiers, printers and other home and office electronic equipments.

The extensive use of power electronic devices to control different loads not only injects the harmonics but also draw substantial reactive power. These unwanted distortions causes many adverse effects like additional heating, amplification of harmonics due to presence of power factor correction capacitor banks, reduction of transmission system efficiency, overheating of distribution transformers, malfunctioning of electronic equipment, spurious operation of circuit breakers and relays, errors in measuring instruments, interference with communication and control signals etc.[3]-[5].

The requirements of power quality at the input of the ac mains, several standards [5], have been developed and imposed on the consumers. The realization of these standards and guidelines such as IEEE-519-1992/ IEC 61000 has attracted the attention of both utility and consumer to share their responsibilities, to keep the harmonics contamination within acceptable limits. Harmonics problem are usually resolved by the use of conventional passive and active filters. Conventional passive filters, namely LC passive filters, possess the merits such as the simple structure, low cost and can compensate reactive power along with harmonics [2],[3]. But PF based on resonant principle have many disadvantages, such as large size, fixed compensation, tuning problems etc., [2].To overcome aforesaid problems, active filters came into picture to provide appropriate solution best suited to the compensation necessities under dynamic load conditions [2]-[4]. However, APFs topologies are not cost effective for high power applications due to their large rating and high switching frequency requirement of the PWM inverters [7]. Therefore, during the last few years many different topologies of hybrid filters are studied [6]-[8]. Hybrid power filter (HPF), consist of passive and active filters combine the advantages of passive and active filters to meet out the requirements of wide range of dynamic compensation[14], [15].

## II. Hybrid Power Filter Configuration

A schematic diagram of a single-phase HPF which consists of an active filter in parallel with two single tuned passive filters is shown in Fig.1 and 2. A single-phase voltage source supplying power to nonlinear load is connected in parallel with a current controlled APF and two single-tuned passive filter. A single-phase full bridge uncontrolled rectifier with R-L load on its dc-side is used as a nonlinear load. The APF consists of an inductor and a half bridge single phase current controlled voltage source inverter with a self-charging capacitor. Random PWM technique is used to obtain the PWM pulses to control the switches used in CC-VSI circuit. The single-tuned passive filters consist of fixed value inductors and capacitors are tuned to compensate 3rd and 5th order harmonics.

Fig. 3 represents harmonic equivalent circuit diagram in which source voltages is considered as an ideal voltage source so it is replaced by short-circuit. Compensation current $i_c$ of APF is given by (1) in which $K_A$ is the overall compensation gain of HPF and $i_{Lh}$ is the load harmonic current.

$$i_c = K_A \, i_{Lh} \tag{1}$$




DOI: 01.IJEPE.03.01.3_1

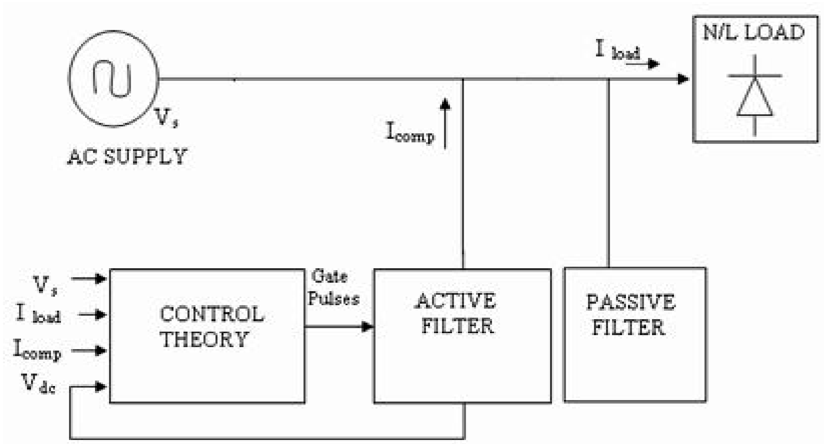


Fig.1. Block Diagram of Hybrid Power Filter

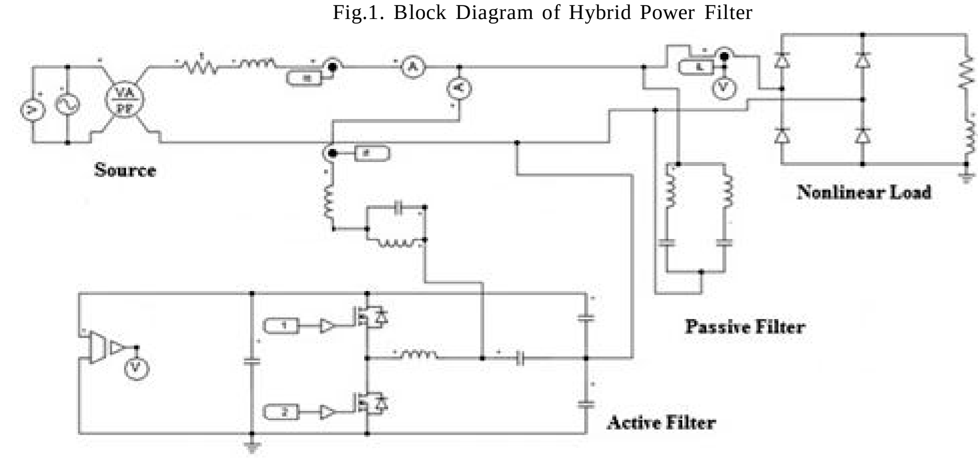


Fig.2. Circuit of Hybrid Power Filter

The source and PF harmonic currents can be determined by (2) and (3) respectively

$$i_{sh} = (1 - K_A)\frac{Z_F}{Z_F + Z_S}\, i_{Lh} \qquad (2)$$

$$i_{Fh} = (1 - K_A)\frac{Z_S}{Z_F + Z_S}\, i_{Lh} \qquad (3)$$

where $i_{sh}$ and $i_{Fh}$ are the harmonic currents through source and PF respectively. For $K_A$ =1, the total harmonic current passed through APF and hence its rating is not reduced.

When $K_A$=0, no compensation through APF, only selected harmonics are compensated through passive filters and rest of the harmonics current is passed through supply source. Therefore, proper coordination between the active and passive filters is very important for reducing the rating of the APF. In the proposed technique the compensating frequency of the active filter is set to ignore the tuned frequencies of the passive filters. The passive filters are used for supplying reactive power and eliminating 3rd and 5th harmonics where as the APF eliminates all remaining harmonics.

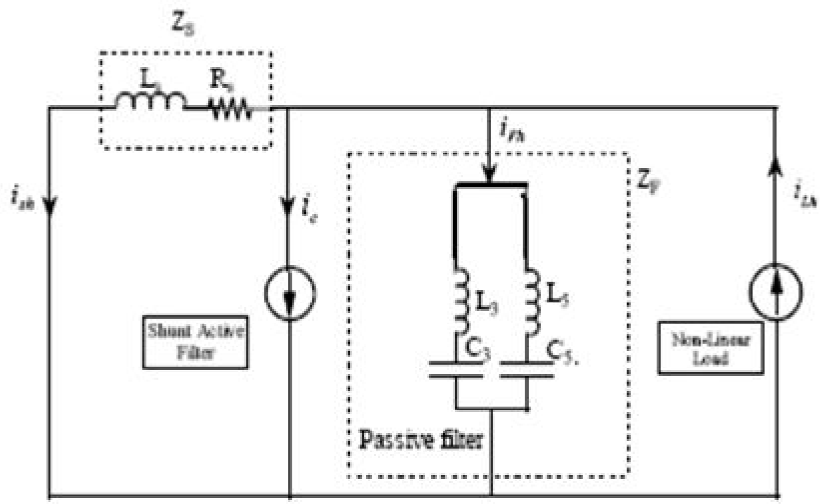


Fig. 3. Equivalent Circuit of HPF




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## III. Active Power Filter Compensation

An active power filter generates a harmonic spectrum that is opposite in phase to the distorted harmonic current it measures. Harmonics are thus

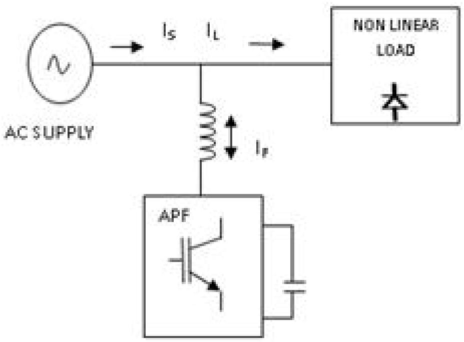


Fig.4. Shunt Active Power Filter

To avoid flowing of the fundamental current of the voltage source to the active power filter, a passive shunt LC filter is used. In the circuit shown in Fig.3 when the S1 is on and the S2 is off, the capacitance C4 is discharged. When the S1 is off and the S2 is on, the capacitance C4 is charged.

$$I_S = I_{load} + I_{filter} \tag{4}$$

$$I_{filter} = I_C \tag{5}$$

The capacitor charging and discharging current is the compensating filter current required to make the supply current exactly equal to the fundamental current cancelled and the result is a non-distorted sinusoidal current. The single leg topology of active power filter and voltage source and rectifier load is shown in Fig. 4.

## IV. Passive Filter Design

Two single tuned passive filter is used to eliminate the 3rd order and 5th order harmonics. The selection of inductance and capacitance has many criteria that should be considered simultaneously. The PF should have an impendence as low as possible at the major harmonics, such as the 3rd and 5th to achieve good filtering characteristics and low power rating of APF. So the capacitance value $C_F$ should be as large as possible whereas the inductance value of $L_F$ should be as small as possible. However, a large capacitance value of $C_F$ will introduce a large amount of capacitive reactive current flowing into the LC filter. Moreover, a low inductance value of $L_F$ would make the LC filter have no capability to suppress the switching ripples caused by the APF. On the other hand, in order to obtain good dynamic characteristics the value of the inductance should be as small as possible. The design result should be a compromise among all the above-mentioned criteria [10], [11].

To suppress 3rd and 5th order harmonic the L and C are tuned at 150Hz and 250Hz. For this PF is tuned at hth harmonic that is:

$$h\omega_1 L_F = \frac{1}{h\omega_1 C_F} \tag{6}$$

$\omega_1$ is equal to $2\pi f$. As a result of a compromise among all the above-mentioned criteria, this paper design the passive filter to tune at 3rd harmonic and selected 11.26mH inductor for $L_F$ and 100µf capacitor for $C_F$. To tune at 5th harmonic 8.11mH inductor for $L_F$ and 50µf capacitor for $C_F$ are selected.

## V. Control Strategy Of Active Power Filter

The active power filter is controlled by means of DC side voltage control algorithm [26]. This theory is based on the voltage value at the capacitors in the DC side of the power inverter. DC side voltage the control is used to estimate the ideal source current. This method uses a proportional integral controller (PI).The adjustment of the PI parameters is important on this theory, since the behavior of the Active Power Filter is hardly dependent of this controller. So the PI response must be fast, enabling the Active Power Filter to quickly respond to load changes, and also must be stable. Oscillations on the response of the PI controller will cause variations in the current amplitude. The value obtained by the PI controller is used to generate a sinusoidal signal that is equivalent to the ideal current at source, necessary to supply the load. To compensate the power factor, the generated sinusoidal signal must be synchronized with the system voltage. This synchronization can be done through a PLL algorithm [18].The load current will be subtracted from the obtained sinusoidal signal to get the compensation current. Fig. 4 shows a block diagram that represents the algorithm used to control an Active Power Filter by the regulation of the DC side voltage.

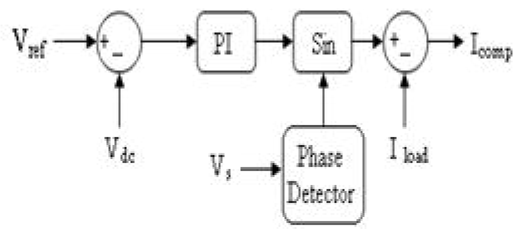


Fig. 5. Block Diagram of Compensation Signal Generation for Control of Active Filter

## VI. Simulation Results Of Hybrid Power Filter

The simulation of hybrid power filter with a shut active and passive filter is done using the PSIM software. The supply voltage amplitude is considered to be 110 V with the frequency of 60 Hz. The source impedance is a series R-L impedance with the values of R = 2.5&! and L = 25µH . The value of reference voltage is chosen as 50V.The values of series L and C in the power converter are selected 100 µH and 3.3 mF respectively. The values of the shunt L, C are chosen 1mH, 4.3mF and the value of series L is selected 1mH. The value of dc capacitor is chosen 4.7 mF and the values of split capacitors are selected as 560µF. The load connected to the dc side of diode rectifier is series R-L with the values of R = 3&!, L =12mH .The simulation of the system is done using PSIM software.


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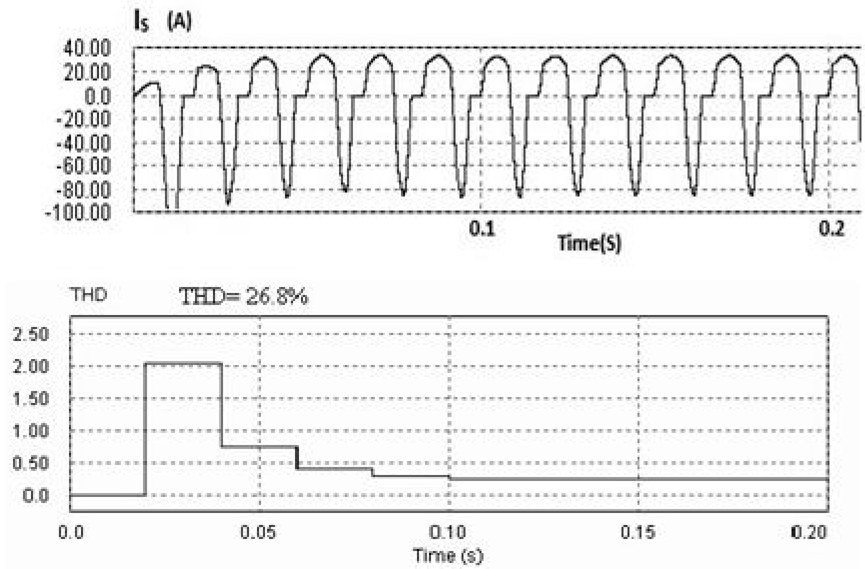

Fig. 6. Source Current, THD of the System Without Filter

The simulation results are shown in Fig.5 to 9.First the simulation results for the system without filter and then with passive filter alone and then with active filter alone are presented and then with both passive filter and active filter that is hybrid filter is presented. The THD of the system when filter is not connected is 26.8% and power factor is 0.93. This is due o the presence of harmonics in source current. When passive filter alone is connected to the system THD get reduced t to 12.4% and power factor is improved to 0.99. This is due to the elimination of 3rd and 5th order harmonics in the source current. Some distortion in source current is due to the presence of remaining harmonic components. When active filter alone is connected to the system THD of source current get reduced to 5.7%. This is due to the compensation of the total harmonic current.

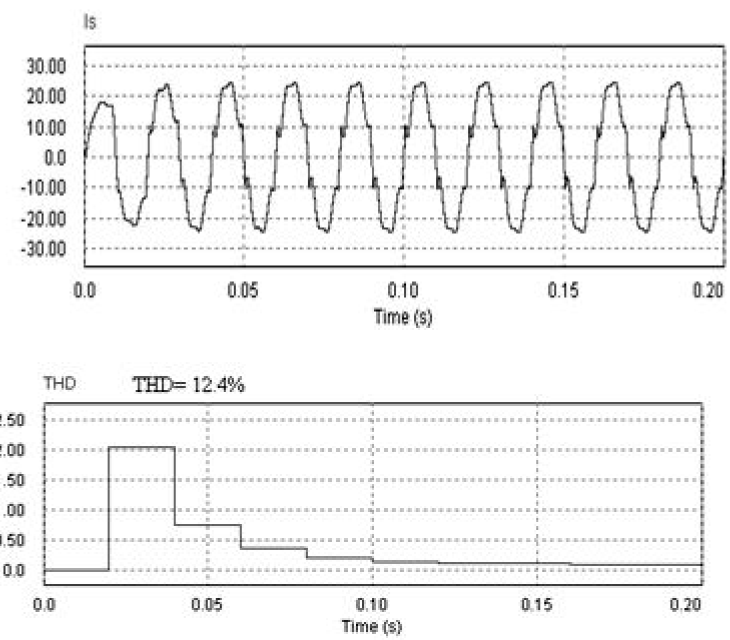

Fig.7. Source current, THD of the system with passive filter alone



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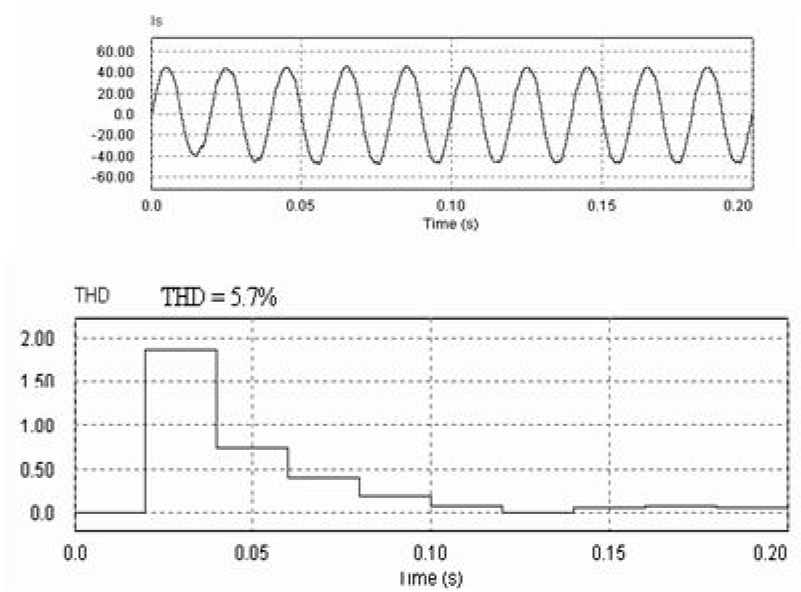


Fig. 8. Source current, THD of the system with Active filter alone

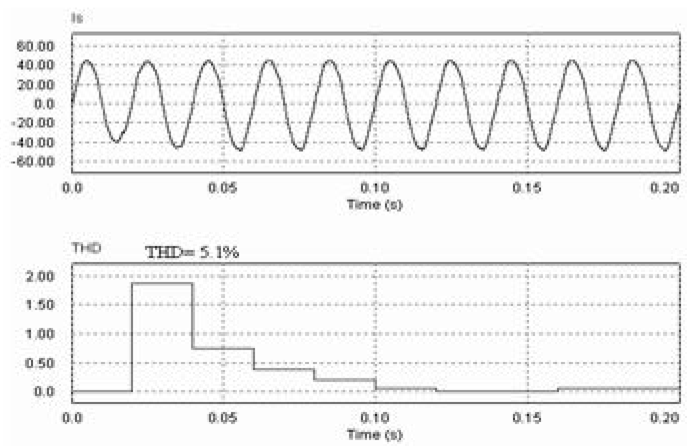


Fig. 9. Source current, THD of the system with hybrid filter

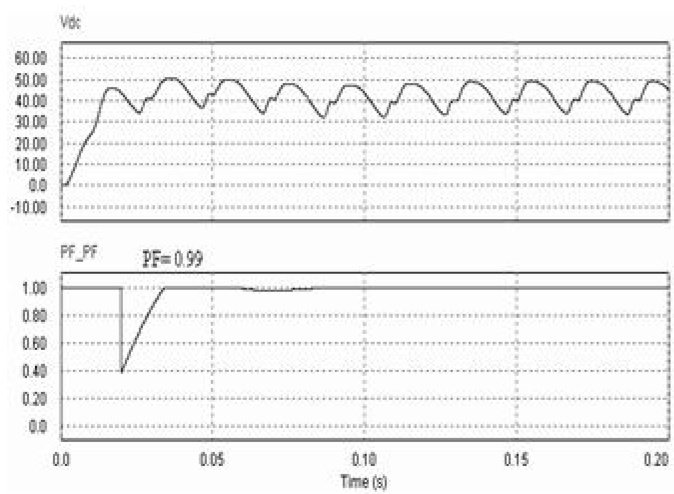


Fig. 10. DC Capacitor Voltage of Active Filter, Power Factor of the System with Hybrid Filter

The phase detection with PLL enables the synchronization of the source voltage and current. The system power factor is improved to a value near to unity. The DC voltage is effectively controlled around the reference value. The reactive power is compensated with the suitable modes of operation of the capacitor in the DC side of the inverter of the Active power filter. The capacitor is charged in one interval and discharged during another interval. The inverter switches provides path for these modes of operation. The reference compensation signal obtained from the controller is the input for the gating of the power switches of the inverter.



DOI: 01.IJEPE.03.01.3_1

The combination of Passive Filter and Active Filter minimizes the Harmonic current components to a permissible limit.With the connection of hybrid power filter THD of source current further get reduced to 5.1%. The improvement in THD for the connection of active filter alone and that of hybrid filter is very small but the addition of passive filter in parallel to active filter reduces the rating and thereby the cost of active filter. The comparison of results is shown in table I.

TABLE I. COMPARISON OF RESULTS

| Case | THD of source current | Input power Factor |
|---|---|---|
| Without filter | 26.8% | 0.93 |
| With passive filter alone | 12.4% | 0.99 |
| With active filter alone | 5.7% | 0.99 |
| With hybrid filter | 5.1% | 0.99 |

## CONCLUSIONS

Hybrid power filter combines the advantages of both passive and active filter for nonlinear load. Its performance in harmonic current compensation is presented in this paper. A simple control scheme of the single phase shunt active power filter is proposed which requires sensing of one voltage and two currents only. The proposed HPF reduces THD of supply current nearly to the prescribed permitted limits specified by IEEE519. The THD of source current is reduced from 26.8% to 5.1%. The quality of the supply is improved so as to meet the requirement of neighboring sensitive loads.The number of switches for the Active Power Filter is reduced. The reactive power compensation provides the improved power factor and also reduces the losses in the electrical devices connected with the system.

## ACKNOWLEDGMENT

The authors wish to thank the management of Kumaraguru college of Technology and JNTU Hyderabad for providing facilities and support.

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DOI: 01.IJEPE.03.01.3_1

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DOI: 01.IJEPE.03.01.3_1